A one step procedure for luting glass fibre posts: an SEM evaluation

S. Grandini, S. Sapio, C. Goracci, F. Monticelli & M. Ferrari
Department of Restorative Dentistry and Dental Materials, University of Siena, Siena, Italy

Abstract

Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M. A one step procedure for luting glass fibre posts: an SEM evaluation. *International Endodontic Journal*, **37**, 679–686, 2004.

Aim To evaluate the ability of two luting procedures for bonding translucent fibre posts to form resin tags, adhesive lateral branches, and resin dentine interdiffusion zones (RDIZ).

Methodology Forty root filled teeth, extracted for periodontal reasons, were selected for the study. The teeth were randomly divided into four groups of 10 each. Group 1: One Step, light-cured (LC) 20 s + dual link resin cement (LC 20 s); group 2: One Step, not light-cured (NLC) + dual link resin cement (LC 30 s); group 3: One Step (NLC) + dual link resin cement (LC 60 s); group 4: One Step (NLC) + dual link resin cement (LC 90 sec). Forty translucent fibre posts (DT posts, RTD) were inserted. Then, root specimens were processed for scanning electron microscope (SEM) observations to assess the continuity of the RDIZ, the presence or absence of gaps and the density and morphology of resin tags using a four-step scale method.

Results With all luting procedures the formation of a RDIZ occurred. However, the microscopic examination of adhesive interfaces revealed that the percentage of RDIZ was significantly higher in group 1 than in the other three groups ($P < 0.05$). Group 4 had a higher percentage of RDIZ than group 3, which in turn exhibited a greater percentage than group 2, but these differences were not statistically significant ($P > 0.05$). Resin tag formation was evident in all the groups. The characteristic reverse cone shape of resin tags was always noted in the coronal and middle third of all groups, and in the apical third of group 1. In the apical third a shorter length and a less uniform appearance of resin tags were noted in groups 2, 3 and 4.

Conclusions In this laboratory study, when bonding a translucent fibre post into a root canal, the luting procedure including light curing of the adhesive solution before the placement of the cement was more satisfactory, from a SEM standpoint, than the procedure involving the simultaneous curing of adhesive and cement (one step procedure).

Keywords: bonding, endodontically treated teeth, fibre post, root canal walls.

Received 5 March 2003; accepted 26 April 2004

Introduction

The potential of fibre-reinforced materials in restorative dentistry has been appreciated for some time (Bradley *et al.* 1980). However, the concept of carbon fibre posts as a method for reconstructing root filled teeth was not described until later (Duret *et al.* 1990). Subsequent research confirmed the retention potential of carbon fibre posts (Asmussen *et al.* 1999, Drummond *et al.* 1999), the low stressing behaviour of the fibre post-resin cement complex, and its good clinical performance (Fredriksson *et al.* 1998, Ferrari *et al.* 2000, Malferrari *et al.* 2002, Scotti *et al.* 2002).

Various changes have been made to fibre post composition, radiopacity, and shape (Love & Purton 1996, Asmussen *et al.* 1999, Vichi *et al.* 2002a). For example, carbon has been replaced by quartz in the fibre composition, and then by glass. The manufacturers have recently developed posts that are radiopaque, allowing them to be seen on radiographs. Several

Correspondence: Prof. Dr Marco Ferrari, Piazza Attias 19, Livorno, 57120, Italy (Tel.: +39 0586 892283; fax: +39 0586 898305; e-mail: ferrarimar@unisi.it).

modifications have been made to post configuration, with the aim of achieving better adaptation to root canal shape.

It is possible to transmit light through a glass fibre post that is translucent. Light transmission through the post might permit a bonding procedure, in combination with an acid-etching technique, based on a light curing adhesive system (as for the other posts) and a dual curing resin cement (Vichi *et al.* 2002a). The translucent fibre post has a modulus of elasticity similar to that of the other fibre posts and of dentine, and offers adequate mechanical properties (Dietschi *et al.* 1997, Asmussen *et al.* 1999). Transmission of light through the post also makes it possible to light-cure the resin cement and the bonding system in only one clinical step ('one-shot'), thus simplifying and shortening the clinical procedure (Lui 1994).

Evaluation of the efficacy of an adhesive system can be performed by observing the uniformity of the resin dentine interdiffusion zone (RDIZ), resin tags, and adhesive lateral branches (Nakabayashi & Pashley 1998), and by recording the presence of voids/bubbles within the luting material or at the interface between the cavity wall and the post (Ferrari *et al.* 2001a). An evaluation of the quality of the RDIZ is not possible using scanning electron microscopy (SEM), rather transmission electron microscopy (TEM) is the appropriate way to assess it (Tay *et al.* 1995).

Recently, the so called 'one bottle' adhesive systems have been proposed for bonding a fibre post into a root canal (Ferrari *et al.* 2001b). In order to perform reproducible studies and to apply a statistical analysis, a method for scoring resin tags, adhesive lateral branches, and RDIZ into root canal etched dentine has been proposed (Ferrari *et al.* 2001a).

The aim of this study was to evaluate the efficacy of a one-step technique ('one-shot') in forming resin tags, adhesive lateral branches and RDIZ when luting translucent fibre posts into root canal preparations. The null hypothesis that the one-step technique creates the same bonding mechanism into root canal dentine than the more traditional two-step luting procedure was tested.

Materials and methods

Forty mandibular anterior teeth (incisors and canines), stored in a 0.1% thymol solution, were randomly selected for the study from the department's stock of extracted teeth. Canal morphology was verified from radiographs (Kodak, Rochester, NY, USA) (70 KV and 0.08 s), taken both buccolingually and mesiodistally. The pulp chambers were opened and canal preparation at a working length 1 mm from the apex was completed to a 35 size master apical file. A step-back technique was used with stainless-steel K-files (Union Broach, New York, NY, USA), Gates Glidden drills size 2–4 (Union Broach). Irrigation was performed using 2.5% sodium hypochlorite and ethylenediaminetetraacetic acid (EDTA) (Glyde File Prep, Dentsply Maillefer, Ballaigues, Switzerland). The prepared teeth were obturated with thermoplasticized, injectable gutta-percha (Obtura, Texceed Corp., Costa Mesa, CA, USA), and resin sealer (AH-26, DeTrey, Zurich, Switzerland).

The root canal walls of each sample were enlarged and the gutta-percha removed with the low-speed drills provided by the manufacturer (RTD, St Egrève, France), to a depth of 9 mm from the cementum-enamel junction. The samples were randomly divided into four groups of 10 specimens each (Table 1).

Group 1

The first 10 specimens were treated with One Step bonding system (Bisco, Schaumburg, IL, USA), following the manufacturer's instructions (Ferrari & Mannocci 2000). The root canal walls were etched with 32% phosphoric acid (Bisco) for 15 s, washed with water by means of a syringe with a small endodontic needle, in order to completely remove the acid, and then gently air-dried. Excess water was removed from the post space using paper points. Four coats of

Table 1 Bonding-luting procedures

Group	Bonding system	Clinical steps	Resin cement	Clinical steps
1	OS	a,b,c,	Duo-Link	d,e,f,g,h
2	OS-30	a,b,	Duo-Link	d,e,f,g,h
3	OS-60	a,b,	Duo-Link	d,e,f,g,h
4	OS-90	a,b,	Duo-Link	d,e,f,g,h

Group 1 (OS) (control): the bonding system was light cured separately for 20 s; group 2 (OS-30): the bonding system was light cured together with the resin cement through the translucent post for 30 s; group 3 (OS-60): the bonding system was light cured together with the resin cement through the translucent post for 60 s; group 4 (OS-90): the bonding system was light cured together with the resin cement through the translucent post for 90 s.
a, Dentine conditioning with phosphoric acid; b, primer application with microbrush; c, light-curing; d, post treated with the primer-adhesive solution; e, mixing resin cement; f, cement application into the root canal with a lentulo drill; g, removing resin excess; h, light-curing through the translucent fibre post.
OS: One-Step (Bisco, Schaumburg, IL, USA); Duo-Link (Bisco).

primer-adhesive material were placed in the root canals with a thin microbrush Plus (Microbrush Co., Greyton, WI, USA) (Ferrari *et al.* 2001b). The excess primer-adhesive solution was removed with a paper point, gently air-dried, and then cured by applying the light tip at the canal orifice, parallel to the long axis of the root for 20 s. For curing purposes, a VIP curing device (Bisco) was used, with a light intensity of 600 mW/cm^2. Duo-Link (Bisco) resin cement, a dual cure resin cement, catalyst and base were mixed and used following the manufacturer's instructions. The resin cement was applied into the root canal space with a lentulo drill, the fibre post was seated, and the excess resin removed and each specimen light-cured for 20 s through the post.

Group 2

Ten root specimens were treated as group 1 samples. The only difference was that the primer/adhesive solution One Step (Bisco) was not cured immediately. Rather, the dual-cure resin cement was applied with a lentulo drill, the post was placed in the root canal preparation, and only at this time were the adhesive material and the cement light-cured simultaneously through the post for 30 s.

Group 3

These roots were treated as described in group 2. The simultaneous light curing was performed for 60 s.

Group 4

These samples were treated as described in group 2. The simultaneous light curing was performed for 90 s.

Double taper (DT) light posts (RTD, St Egrève, France) were used in the 40 samples (Boudrias *et al.* 2001). Depending on the size and the shape of the root specimens, number 1 (tip diameter = 90, taper 06) and 2 (tip diameter = 100, taper 08) DT posts were used. The length of each post was controlled before the luting procedure, and the post was sectioned to match the length to the root canal preparation.

After complete setting of the cement, crown build-ups were performed with the proprietary resin composite (Biscore, Bisco) to eliminate the chance of incompatibility between the luting cement and the core material.

The teeth were stored in water at room temperature for 1 week. The roots were then sectioned parallel to the long axis of the tooth using a diamond saw (Isomet, Buehler, Lake Bluff, NY, USA), at slow speed under water.

RDIZ observations

One section of each root was gently decalcified (32% phosphoric acid was applied for 30 s; the sample was then washed and gently air-dried) and deproteinized (the sample was immersed in a 2% sodium hypochlorite solution for 120 s), in order to evaluate RDIZ formation.

After being extensively rinsed with water, the specimens were gently air-dried and dehydrated with alcohol, sputter-coated with gold (Edwards Ltd, London, UK) and observed under a SEM (Philips 515, Philips Co., Amsterdam, The Netherlands) at ×1010 magnification. The observations were made by two operators, and repeated twice in order to ensure intra examiner consistency. When a different score was given, the lower score was taken into account.

The following aspects were evaluated by SEM:

1 The continuity of the RDIZ: this variable was assessed as the percentage ratio between the length of the RDIZ and the total length of the adhesive interface using a visual and computer aided examination and calculation. The differences among the average ratios calculated for the four groups were tested for statistical significance. The one-way ANOVA and Newman–Keuls multiple comparisons test were applied, setting the level of significance at $P = 0.05$.

2 The presence or absence of gaps: (i) inside the adhesive layer, (ii) between the adhesive and the resin cement layer, (iii) inside the resin cement layer, and (iv) between the adhesive and the post.

Evaluation of resin tag formation

The other section of each sample was stored in 30% HCl for 24 h and in 2% sodium hypochlorite solution for 10 min, in order to completely dissolve the dental substrate and to detect resin tags and adhesive lateral branch formation. The samples were then processed for SEM observation as already described.

Serial SEM photomicrographs at ×500 original magnification were taken of the canal walls at the 1, 4.5 and 8 mm levels from the end of the post. The serial photomicrographs were aligned to form a continuous horizontal examination strip at the three levels. Irrespective of the number of photomicrographs needed to form a complete strip, each strip was subdivided into

eight 'assessment units'. The density and morphology of the resin tags were then assessed.

The density and morphology of resin tags present at ×500 magnifications were graded between 0 and 3. A score of 0 was assigned where resin tags were not detectable, a score of 1 was recorded when few, short resin tags (resin plugs) were visible. A score of 2 was recorded when uniform resin tags formation was seen but with a few lateral branches. A score of 3 was recorded when long resin tags with lateral branches were uniformly evident.

Higher standardized magnifications were taken in order to document resin tags and adhesive lateral branches morphology.

The scores assigned to resin tags seen at the 1, 4.5, and 8 mm levels were analysed with the Kruskal–Wallis test, in order to check for statistical significance of the differences both within and among the groups. The level of significance was set at $P = 0.05$ level.

Results

The number of samples showing voids/bubbles within the resin cement or/and at the interface between resin cement and root walls are summarized in Table 2. Voids were present in the composite cement layers of all groups. The cement layer was substantially similar in all groups. Between 10% (group 1) and 30% (group 3) of samples showed bubbles/voids within the cement. The adhesive–composite cement and composite cement–fibre post interfaces were substantially free of voids. Half of the samples in group 2 showed voids/bubbles in the adhesive/cement layer. All groups with simultaneous curing of the adhesive and of the cement (groups 2, 3 and 4) showed a high number of voids in post/cement and adhesive/cement interfaces.

Table 2 Number of specimens in which the presence of gaps/voids/bubbles within resin cements was noted

	Within resin cement	Post/cement	Adhesive/cement
Group 1	1	1	–
Group 2	2	1	5
Group 3	3	2	3
Group 4	2	2	2

Table 3 Scanning electron microscope evaluation of the resin dentine interdiffusion zone (RDIZ). (Groups labelled with the same letter did not show any statistically significant difference)

Group	Overall length of observed interface (in mm)	Length of interface with RDIZ [in mm (%)]
1 (OS)	25.5	22.7 (89)[a]
2 (OS-30)	26.5	18.5 (60)[b]
3 (OS-60)	27.0	18.5 (65)[b]
4 (OS-90)	26.0	18.2 (70)[b]

Group 1 (OS) (control): the bonding system was light cured separately for 20 s; group 2 (OS-30): the bonding system was light cured together with the resin cement through the translucent post for 30 s; group 3 (OS-60): the bonding system was light cured together with the resin cement through the translucent post for 60 s; group 4 (OS-90): the bonding system was light cured together with the resin cement through the translucent post for 90 s.

Figure 1 Interface between root dentine and bonding material at the middle third of a group 2 sample (original magnification ×1010). An evident gap is present.

Resin dentine interdiffusion zone observations

The results obtained regarding the presence of RDIZ in the various groups under the SEM microscope are shown in Table 3. The ratio between the length of the RDIZ and the total length of the interface was significantly higher in group 1 than in the other two groups ($P < 0.05$). Group 1 samples had uniform RDIZ formation, while in the other groups RDIZ was less represented, especially at the apical level. In some samples of group 2 (Fig. 1), 3 (Fig. 2), and 4, a discontinuous gap between the RDIZ and resin cement was observed. The RDIZ formation of group 1 samples was significantly more evident than in the other three groups (groups 2, 3 and 4). Group 4 (Fig. 3) showed a higher ratio than group 3, which in turn presented a higher ratio than group 2, but no statistically significant differences were found among these three groups ($P > 0.05$).

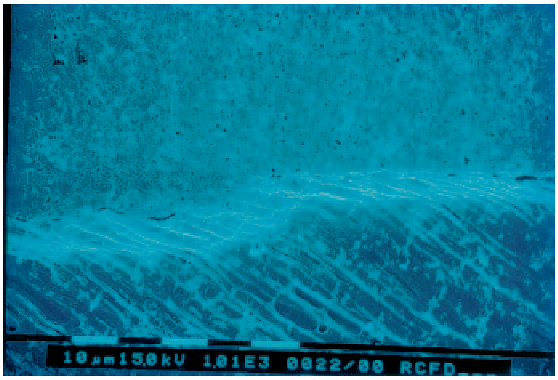

Figure 2 Middle third, group 3 sample (original magnification ×1010). Uniformly formed resin tags and RDIZ are visible. Small discontinuities between RDIZ and resin cement are noted.

Table 4 Median values of the resin tags formation scores recorded at 1-, 4.5-, and 8 mm levels. (Groups labelled with the same letter did not show any statistically significant difference)

Group	1 mm level (coronal third)	4.5 mm level (middle third)	8 mm level (apical third)
1 (OS)	2.9^{a}	2.9^{a}	$2.5^{a,b}$
2 (OS-30)	$2.6^{a,b}$	2.4^{b}	1.1^{d}
3 (OS-60)	$2.6^{a,b}$	2.5^{b}	$1.3^{c,d}$
4 (OS-90)	2.7^{a}	$2.5^{a,b}$	1.7^{c}

Group 1 (OS) (control): the bonding system was light cured separately for 20 s; group 2 (OS-30): the bonding system was light cured together with the resin cement through the translucent post for 30 s; group 3 (OS-60): the bonding system was light cured together with the resin cement through the translucent post for 60 s; group 4 (OS-90): the bonding system was light cured together with the resin cement through the translucent post for 90 s.

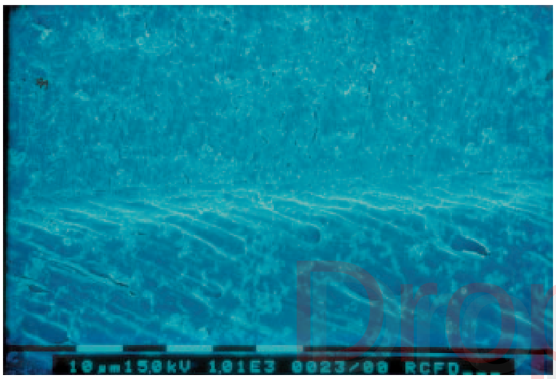

Figure 3 Middle third of a group 4 sample (original magnification ×1010). RDIZ and resin tags formation is evident.

Figure 4 Short resin tags at the middle third of a group 3 sample (original magnification ×503).

Evaluation of resin tag formation

The results obtained regarding morphology and density of resin tags are summarized in Table 4. In group 1 resin tags and lateral branches formation was more uniform than in the other groups. Although the length of resin tags was more evident at the coronal third, the morphology of the resin tags was similar in all three thirds. The surface of resin tags reproducing demineralized tubular dentine was rough and depicted the appearance of tubular dentine dissolved by the acid. In the apical third resin tags were all approximately the same length, which was shorter than that seen in the coronal and middle third.

Group 2, 3 and 4: the resin tags formed in the coronal and/or middle areas of the roots were much longer than those in the apical areas. Also, the density of resin tags was higher in the coronal and middle areas than in the apical areas (Figs 4 and 5). In the coronal two thirds of the roots adhesive lateral branch formation was also observed. In the coronal and middle third the resin tags had a characteristic reverse-cone shape, while in the apical third this morphology could only occasionally be seen (Fig. 4). In the apical third resin tags were often seen to only plug the tubules or were completely absent. In groups 2, 3, and 4, some 'globuli' were observed (Figs 6 and 7). Resin tag formation was statistically significant different ($P < 0.05$) between group 1 and the other three groups.

Discussion

Recently, several studies have reported the quantitative evaluation of morphological observations of root canals

Figure 5 Group 4 sample, middle third (original magnification ×503). Resin tags formation is clearly evident.

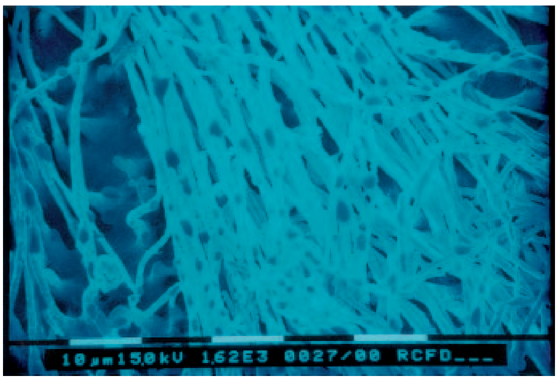

Figure 6 Group 4 sample, apical third. Resin globuli closely attached to the resin tags are noted (original magnification ×1620).

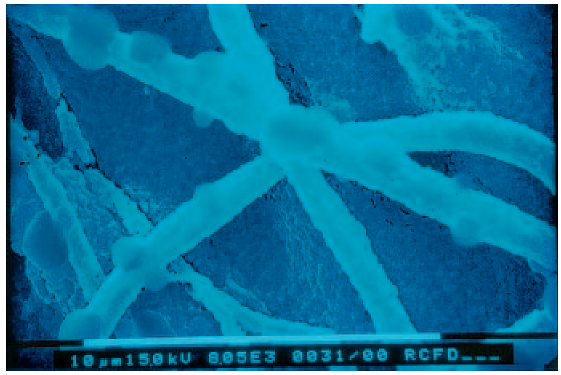

Figure 7 Higher magnification of Fig. 6(a) (original magnification ×8050). These globuli, probably formed by unpolymerized resin, can be because of an incomplete curing of the adhesive material when it is not light cured before the placement of the resin cement and the post.

(Ferrari *et al.* 2001a,b). In this study, RDIZ formation was evaluated calculating the entire length of RDIZ formed along the interface between conditioned dentine and adhesive resin. Also the incidence of resin tags was recorded from horizontal bands around the post, 1-, 4.5- and 8-mm from the apices of the root canal preparations. In this way it was possible to statistically analyse the data obtained from SEM observations of the four different groups. This evaluation was performed because formation of both resin tags and RDIZ contribute to the mechanical bonding process to the etched dentine and consequently to the sealing process (Nakabayashi & Pashley 1998, Vichi *et al.* 2002b). However, other issues have to be taken into account (Sano *et al.* 1995a, Tay *et al.* 1995): the 'overwet phenomenon' plays an important role in the quality of the RDIZ, and subsequently in the final bond strength of the adhesive system. In this paper no TEM examination and no measurement of the bond strength were performed (Sano *et al.* 1995b, Tay *et al.* 1996).

After light curing the bonding system from the coronal aspect of the canal (group 1), the dentine bonding systems tested could form a RDIZ that did not interfere with the post placement into the root canal. This is most likely because of the fact that the 'one-step' bonding system tested in this study created a low film thickness (Vichi *et al.* 2002a) and the bonding system was light sensitive and could be polymerized by a light source placed at the access to the root canal (group 1). In groups 2, 3 and 4, One Step (Bisco, Schaumburg, IL, USA) was not light cured before applying the resin cement and the post, but adhesive materials were light-cured through the post simultaneously, shortening the clinical procedure.

An important issue related to the clinical procedure is the care taken to remove excess adhesive that, once cured, could interfere with the adaptation of the post to the prepared dowel space. Although all the samples were prepared by the same operator, following the same procedure and using the same instruments, some variability in the cement thickness was expected and actually observed as a result of the naturally occurring variability in root canal shape.

It is always questionable whether an interfacial gap seen under the SEM is an artefact because of specimen preparation. However, as most of these gaps were consistently and locally concentrated in the apical third, the least accessible area of the canal, it can be speculated that they were real gaps revealing an adhesion mechanism of poor quality.

A different density and morphology of resin tags and adhesive lateral branches at the three horizontal bands could be found in group 1 as compared with group 2, 3 and 4 samples. These three last groups always had poorer results when compared with the standardized technique for bonding fibre posts into root canals (group 1). Even when the exposure time to the light curing procedure was increased (groups 2, 3 and 4, from 30 to 60 and 90 s respectively), the increase in the scores was not statistically significant. Group 1 samples always had better results than samples from the other three groups. This may be because of a difference in the procedure, for example, although it has been demonstrated that a proper light curing of resin cement can be obtained in an experimental model (Boschian *et al.* 2001), it is possible that light transmission through the post might not be sufficient to light-cure the cement and the adhesive in the same step. The adhesive may be subjected to an inadequate intensity of light and thus not be completely cured, thus leaving 'unpolymerized' adhesive resin. Even when increasing the light-exposure time, from 30 s (group 2) to 60 s (group 3) and to 90 s (group 4), uncured resin globuli were still present. This could account for a reduction in resin tag formation and the poor results presented in Table 4. This problem is supported by the finding of other studies (Tay *et al.* 1995).

Another factor affecting RDIZ and resin tag formation can be the viscosity of the cement and its adaptation to prepared canal space. If the adhesive solution is not light-cured before the application of the cement, a good adaptation to the root canal walls is not achieved, and the RDIZ is not established adequately. Under these conditions, when the cement is placed together with the post, the cement itself may wash out the adhesive.

In all the four groups a microbrush was used. The importance of this device in reaching the narrowest and deepest portions of the root canal preparations has been showed by recent findings (Ferrari *et al.* 2001b, Vichi *et al.* 2002b). The microbrush is able to reach all the prepared root canal dentine, and to apply a certain pressure on the adhesive solution, so as to maximize its penetration into the etched substrate. This results in a deep diffusion of resin into the tubules and in the formation of lateral branches (Chappel *et al.* 1994, Mjor & Nordhal 1996).

The absence of voids/bubbles at fibre post/resin cement interface could be related to the good bond between the resin matrix of the post and that of the resin cement, whereas the presence of voids/bubbles within the resin cement might be mainly because of the viscosity of the resin cement and to the anatomy of the root samples. In fact, anatomical variations of roots, the consequent variable amount of resin cement, and its distribution into a prepared canal space could be other possible causes of void formation. Discrepancies between root anatomy and post shape might account for the clinical finding that the weakest point of fibre post/resin cement/adhesive material/etched dentine system is the link between resin cement and the post (Ferrari & Scotti 2002). The high percentage of voids/bubbles found in group 2, 3 and 4 shows that several factors (light intensity, cement viscosity etc.) interfere with the complete setting of the materials used, as compared with group 1, where a traditional technique was used and a lower number of voids were detected. No data are available regarding a calculation of the percentage of light passing through the post and reaching the apical area. However in order to improve the predictability of the one-step technique, it would be desirable for the manufacturers to provide translucent posts able to transmit a high intensity of light from coronal to apical areas. Of course, the amount of light emitted by the light source is important, ideally the light transmitted to the post should be such as to ensure an adequate degree of polymerization in the apical third, without resulting in an augmented polymerization shrinkage in the presence of unfavourable configuration factor that occurs in the root canal (Feilzer *et al.* 1987).

The microscopic observations in this study and their quantitative evaluations does not provide information on the quality of RDIZ. It has been shown recently (Mason 2001) that collagen fibres can be denaturated in direct correlation with the time passed after root canal treatment. In recently treated teeth a wide and dense collagen fibre network could be noted. On the contrary, when the treatment had been performed more than 5 years previously, the collagen fibres appeared shorter, and their organization and uniformity was lost. This denaturation of collagen fibres can be related to the loss of organic tissue turnover after root canal treatment.

Conclusions

The null-hypothesis tested in this study was not confirmed. The one-step ('one-shot') technique, used for luting translucent fibre posts into root canal

preparations proved to be less effective than the traditional technique in forming resin tags, adhesive lateral branches and RDIZ.

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